The Action of Cutting Tools.

By Prof. E. G. COKER, F.R.S.

ENGINEERING activity is so largely dependent on the action of cutting tools, that it is not surprising to find a very large amount of research work has been devoted to its study, and at the present time there are in England two committees actively pursuing researches in this field, in addition to private investigators. At the suggestion of the Cutting Tools Research Committee of the Institution of Mechanical Engineers, of which Sir John Dewrance is chairman, some experimental studies of a preliminary character have been made recently at University College, London, on transparent bodies subjected to the action of cutting tools, and the double refraction produced by stress has been used to measure the stress distribution in the cut material. Similar experiments have also been carried out on some glass-cutting tools used for turning and planing operations.

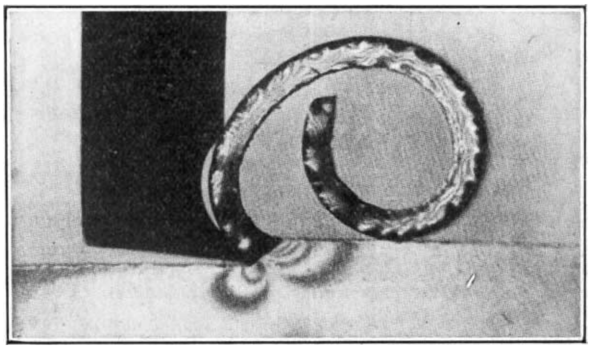


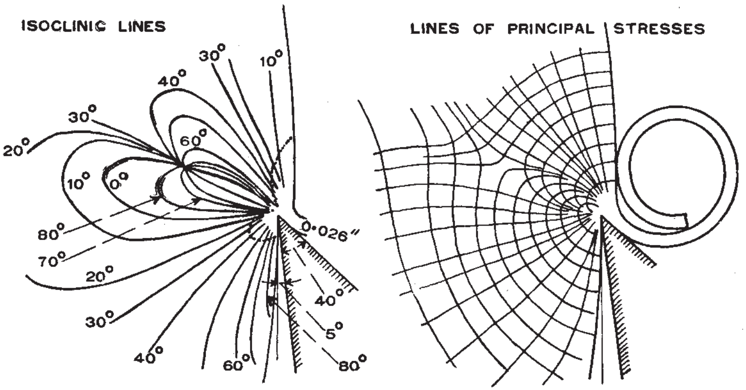
FIG. 1.—Steel tool planing a strip of nitro-cellulose.

The photo-elastic method has many advantages over direct experiment on metals, as up to and, in fact, well beyond the elastic limit of the transparent nitro-cellulose used, the stress distribution produced can be measured with considerable accuracy at all points in a disk or flat plate under the action of a tool. The optical effects give, at once, a measure of the difference of the principal stresses at a point, the lateral contractions afford a measure of their sum, and the isoclinic lines map out the directions of the stresses. Existing literature shows how very difficult it is to obtain similar information from the metal itself when under the action of a tool. Since the distributions are similar up to the elastic limit of each material, owing to the absence of elastic constants in the fundamental equation $\nabla^4 \cdot \chi = 0$, there are obvious advantages in a study of the characteristics of cutting tools by these means. The general phenomena observed when a tool is cutting are shown in Fig. 1, where a steel tool is planing a plate of nitro-cellulose in a circularly polarised field of light. It will be observed that colour bands spring from the cutting edge of the tool and curve round in approximately circular arcs to meet the boundary, indicating the existence of variable radial compression stress in the area in front of the tool, and a similar state of tensional stress behind it.[1] Measurements of the principal stresses and their inclinations show that this is approximately what obtains, and a very fair idea of the stress conditions in the material can be obtained from the photograph if radial lines are drawn in all directions from the point of the tool to intersect the colour bands. The outer bands pass through all points at which the stress is 1150 pounds per square inch, for the sharply defined boundary between the purple and the blue, and the succeeding ones reckoning inwardly mark stresses of twice and three times this value. The fourth band indicates possibly a somewhat different stress intensity than its numerical order warrants, owing to its close proximity to the black area in which intense plastic stress is developed at and near the cutting edge of the tool. An interesting feature is the partial recovery of the material, for the black area is met with only at this place. The shaving again shows brilliant colour effects after it has finally left the tool, but later becomes obscured, again owing to the further curl developed due to contact with the parent material.

Careful measurements show, however, that the actual state of stress, excluding the plastic field, is somewhat more complicated. The stress is never quite radial, and the isoclinics are therefore not straight lines, but are always curved somewhat, as indicated in Fig. 2, which shows a set of isoclinics obtained from a disk of about six inches in diameter when subjected to the action of a turning tool with a somewhat acute cutting angle. The lines of principal stress confirm this, and the valves of the minor principal stresses appear to be small in the cases examined so far, and to a first approximation the distribution of principal stresses $\widehat{RR}$ and $\widehat{\Theta\Theta}$ may be taken to be of the type

$$\widehat{RR} = (-2P/\pi) \cdot \cos\theta/r$$

where $\widehat{\Theta\Theta}$ is small, and the angles are measured from the radial black brush dividing the tension from the compression area. The position of this latter brush



Dotted line shows position of the red band of 1st order.

FIG. 2.—Isoclinics and lines of principal stress in a disk under the action of an edge-turning tool. From the Proceedings of the Institution of Mechanical Engineers, by permission of the Council.

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[1] "An Account of some Experiments on the Action of Cutting Tools," by Prof. E. G. Coker and Dr. K. C. Chakko, Proceedings of the Institution of Mechanical Engineers, 1922.

depends on the cutting angle of the tool, and also upon its rake and clearance, but investigation has not proceeded far enough as yet to define accurately the influence which each element has upon its position.

A somewhat remarkable change from these conditions is produced when the cutting edge is not so perfectly sharp as it is possible to make it. It then becomes apparent that the shaving is no longer cut from the main body, but is broken or torn away by the continual forcing of a wedge between the shaving and the main body of the material, after the latter has once been penetrated. The shaving breaks away at a point A above the cutting edge (Fig. 3), mainly owing to the bending action exerted by the raking face of the tool, and is so much overstressed at this place that all colour effects are obliterated. An intense and permanent black patch is therefore produced separated by a less stressed part B, in which plastic stress colour effects are observable from a similarly much more overstressed part C immediately preceding. These effects are repeated at regular intervals as is indicated in Fig. 3 in a somewhat diagrammatic form, and are accompanied by a rhythmic pulsation of the colour bands in phase with this phenomenon. The tearing away of the shaving in this manner produces a rough uneven surface on the material, which in planed work is therefore not truly flat, and in turned work is not perfectly cylindrical. It is probable that this influences the character and kind of chip produced in brittle materials, as it undoubtedly influences the shaving from an elastic material which is capable of assuming a plastic condition. Moreover, it is sometimes found that when this latter condition occurs the tool is acting in a two-fold capacity, for not only does it break off a shaving, but it may also pare off the irregularities as the point of the tool comes in contact with them, so that occasionally a second and much thinner shaving, D, is produced, and peeled off as indicated in Fig. 3, by a true secondary cutting action. Double shavings are sometimes produced in this manner when steel is turned in a lathe, and it is probable that the fine powder, which can often be observed falling away from a tool working on cast iron, is due to this secondary cutting action.

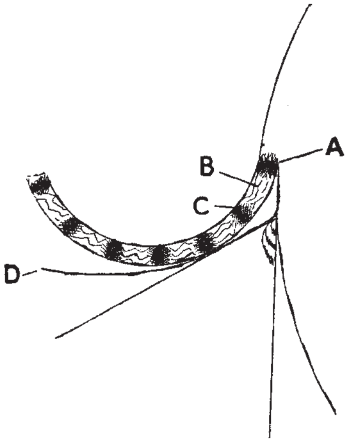

FIG. 3.

In tools with multiple cutting edges the same general features of stress distribution are observed in the material. They are sometimes accompanied by additional phenomena, as, for example, with the milling cutter, shown in Fig. 4, where the depth of cut is variable owing to the uniform movement of the material up to the cutting edges, which are also turning at a definite and uniform rate. The shaving cut from the trochoidal contour is continuously increasing in thickness therefore, as the cut advances, and in the present instance is being torn off rather than cut, as the characteristic markings for this kind of action occur in a very pronounced manner. If sufficient travel is given to the work, the separate lobed colour bands springing from each cutting edge, and denoting approximate radial stress, ultimately coalesce before

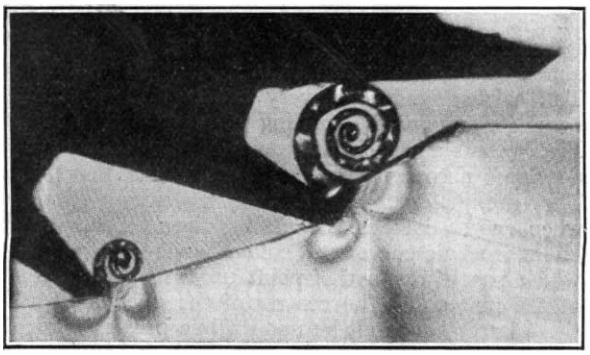

FIG. 4.—Steel milling cutter operating on a plate of nitro-cellulose.

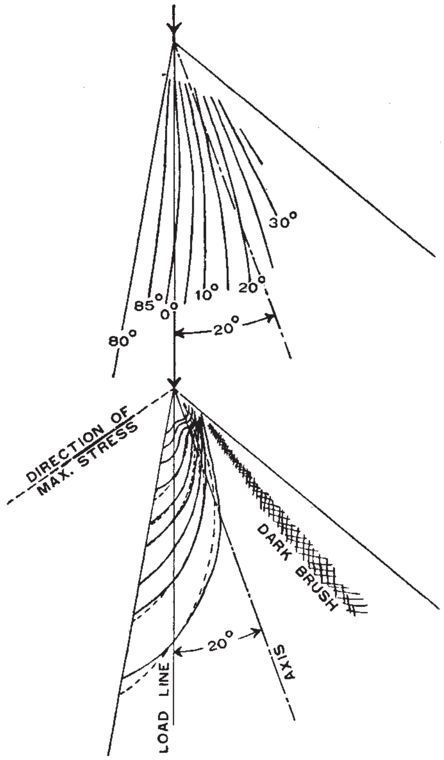

FIG. 5.—Isoclinic lines and colour bands observed and calculated for a wedge of angle 60° when a load of 50 pounds is applied at an angle of 20° with the axis. Colour bands observed are shown in full lines; equivalent stress lines given by theory are shown dotted. From the Proceedings of the Institution of Mechanical Engineers, by permission of the Council.

the end of the cut, and the stress distribution becomes much more complicated.

The stress in glass tools when cutting nitro-cellulose has been studied, and it is found that when the material is being removed in a thin shaving by a true cutting action the stress system is of a simple radial type. The colour bands are very nearly arcs of circles passing through the cutting edge as indicated in Fig. 3, and are such as would be produced by the action of a concentrated force applied at this place. They are, in fact, of the same type as those obtained when a non-axial force is applied at the apex of a wedge, giving isoclinic curves and colour bands (Fig. 5), all of which pass through this point up to the yield point of the material. The centres of the circular arcs of these latter bands all lie upon a line passing through the apex and perpendicular to the dark band shown in Fig. 5, which marks the region of no stress. They are, therefore, approximately consistent with Michell's theory of stress in a wedge,[1] and have been shown experimentally, in the paper referred to above, to be in good agreement therewith along the line of action of the applied force. The stress system is found to be almost entirely radial and expressed by

$$\widehat{rr} = -c \cdot \frac{\cos(\alpha - \phi)}{r},$$

along this line—where α is the inclination of the outer face to the line of centres of the colour bands, and ϕ is the inclination of the applied force to the same face. Along each colour band $\widehat{rr}$ is practically constant. The value of the constant c is also expressible in terms of the force P, the angle α and the angle γ of the wedge. The stress system in the case when the material is being torn off by the action of the raking face of the wedge angle of the tool has not, so far, been made out. Experiment shows, however, that it is of a more complicated type, especially when the action is accompanied by the building up of a secondary wedge on the tool from the material torn off in a manner which is familiar to those engaged in machinery operations involving heavy cuts.

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[1] Proceedings of the London Mathematical Society, vol. xxxiv., 1902, and Love's "Theory of Elasticity," 2nd edition, pp. 208-209.

The New Building of the National Academy of Sciences, U.S.A.

By Dr. C. D. WALCOTT.[1]

IN 1863 Henry Wilson, United States Senator from Massachusetts, asked a number of men eminent in science to come together to form an organisation by which the scientific strength of the country might be brought to the aid of the government. This meeting was directly the result of an Act of Congress passed March 3, 1863, incorporating the National Academy of Sciences of the United States of America. While Senator Wilson presumably had aid and suggestions from the incorporators, the bill had its inception with, and was drawn by him, and did not incorporate the Academy in any state or territory, or in the District of Columbia. It seems to have been his idea that the Academy should be national in its broadest sense.

The Academy has held its annual meetings in Washington at the Smithsonian Institution and its autumn meetings in other cities. Joseph Henry was president for many years and at the same time secretary of the Institution. The records and library of the Academy have been stored in several hundred boxes at the Institution, awaiting such time as the Academy may have a building of its own where this material can be made available.

The semi-centennial in 1913 gave new life to the activities of the Academy, and the foreign secretary, Dr. George E. Hale, proposed then that the Academy should have a home. He prepared tentative plans and had them put in shape by an architect. These plans provided laboratories and a library for the use of the Academy and resident men of science for research work.

The project was not to be long delayed, for the world war coming in 1914 changed and broadened the thought of the world. What started to be a battle of armed forces turned to competition between the countries at war in creative scientific research, looking to the destruction of masses instead of individuals. This led to the need in the United States of a body that could bring together the most able men in the fields of science for the solution of war problems. Dr. Hale, conceiving the need for such a service long before it was an actual necessity, proposed that the Academy take preliminary steps in the organisation of the scientific resources of the United States, and this was the beginning of the National Research Council which rendered such effective service at the request of the President of the United States during the war.

Appreciation of this service from the Academy was shown in an executive order issued by President Wilson, directing the National Academy of Sciences to continue the Council. Under this order the Research Council was reorganised on a permanent peace basis as an agent of the Academy, and the need of the Academy for a home was accentuated. Dr. Hale's precious plans were discussed at length, but the question of available funds continued. The quarters in the Smithsonian Institution, already too crowded, could not afford room for this new body, and temporary space elsewhere was found in the Munsey Building; then a residence at 16th and L Streets, having twenty-one rooms, was secured. A little later a larger building at 16th and M Streets was occupied, until the present location at 17th and Massachusetts Avenue was leased.

Early in these renewed activities strenuous efforts were made to secure a permanent endowment and money for a building for the Academy, and a suggestion was made to the Carnegie Corporation of an endowment and building for the Academy and Research Council, resulting in an offer of 5,000,000 dollars, provided the Academy would secure a site and present satisfactory plans. The amount needed for the purchase of this site was apportioned, so that the entire country might have a part in the great enterprise. The raising of funds for the purchase of the

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[1] Paper read before the National Academy of Sciences on April 24.